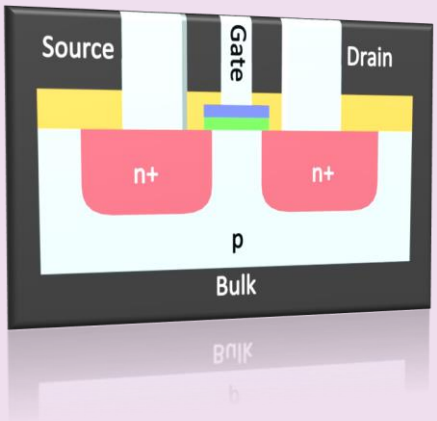
Physics Academy

www.physicsacademy.org

Electronic Fundamentals

Circuits, Devices, and Applications



Unit 6: Field Effect Transistor (FET)

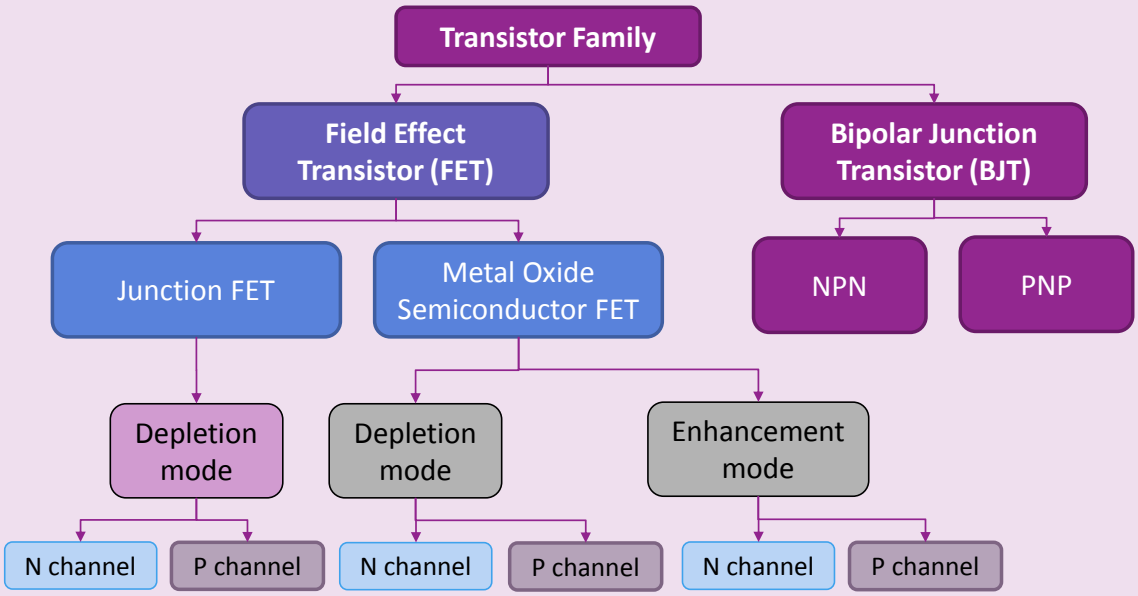
Lecture 20: Metal Oxide Semiconductor FET (MOSFET)

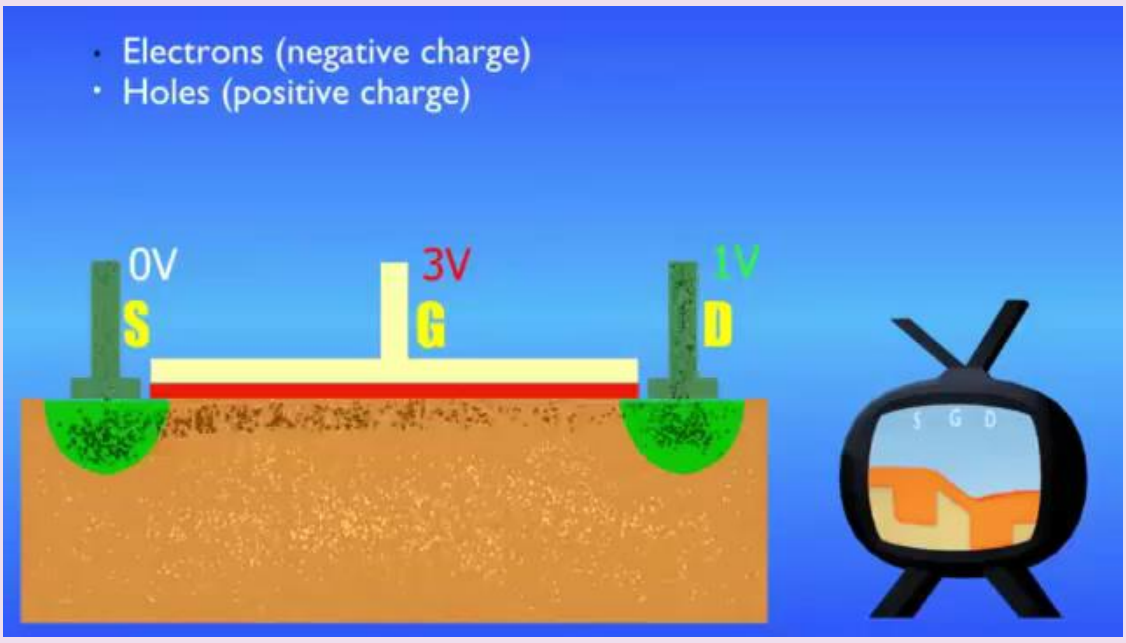
Dr. Hazem Falah Sakeek

Al-Azhar University of Gaza

Introduction

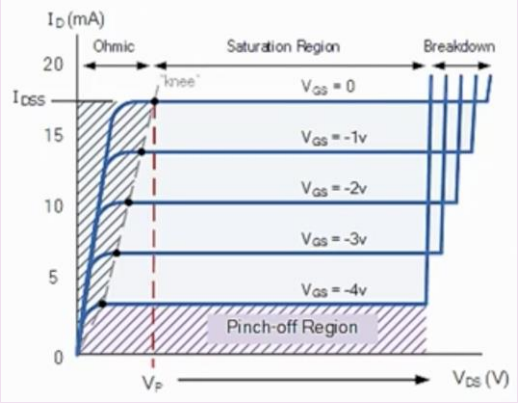
- The **MOSFET** (**m**etal **o**xide **s**emiconductor **f**ield-**e**ffect **t**ransistor) is another category of field-effect transistor. The MOSFET, different from the JFET, has no *pn* junction structure; instead, the gate of the MOSFET is insulated from the channel by a silicon dioxide (SiO_2) layer.
- A *MOSFET* is an important semiconductor device and can be used in any of the circuits covered for *JFET*. However, a *MOSFET* has several advantages over *JFET* including high input impedance and low cost of production.


Transistor Family
Field Effect Transistor (FET)
Bipolar Junction Transistor (BJT)
Junction FET
Metal Oxide Semiconductor FET
NPN
PNP
Depletion mode
Depletion mode
Enhancement mode
N channel
P channel
N channel
P channel
N channel
P channel


Electrons (negative charge)
Holes (positive charge)
0V
3V
1V
S
G
D

Drawback of *JFET*

- The main drawback of *JFET* is that its gate *must* be reverse biased *i.e.* it can only have negative gate operation for *n*-channel and positive gate operation for *p*-channel.
- This means that we can *only* decrease the width of the channel from its zero-bias size.
- This type of operation is referred to as *depletion-mode* operation. Therefore, a *JFET* can only be operated in the depletion-mode.



A field effect transistor (FET) that can be operated in the enhancement-mode is called a MOSFET.

Types of MOSFETs

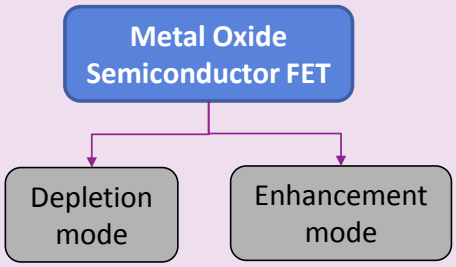
There are two basic types of *MOSFETs viz.*

1. Depletion-type *MOSFET* or ***D-MOSFET.***

The *D-MOSFET* can be operated in both the depletion-mode and the enhancement-mode. For this reason, a *D-MOSFET* is sometimes called depletion/enhancement *MOSFET*.

2. Enhancement-type *MOSFET* or ***E-MOSFET.***

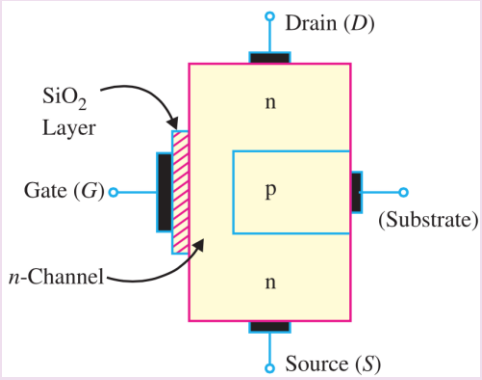
The *E-MOSFET* can be operated *only* in enhancement-mode.



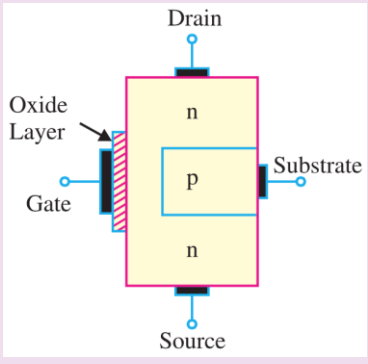
The manner in which a *MOSFET* is constructed determines whether it is *D-MOSFET* or *E- MOSFET*.

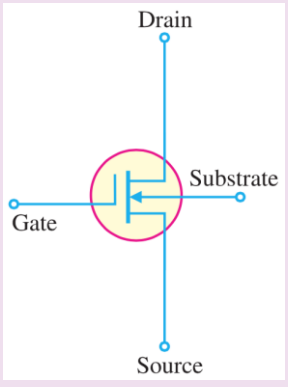
D-MOSFET

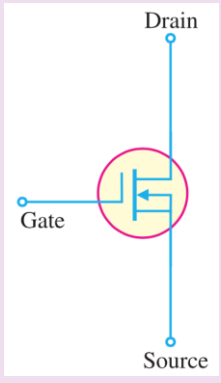
The *n*-channel *D-MOSFET* is a piece of *n*-type material with a *p*-type region (called *substrate*) on the right and an *insulated gate* on the left. The free electrons flowing from source to drain must pass through the narrow channel between the gate and the *p*-type region (*i.e.* substrate).



Symbols for D-MOSFET



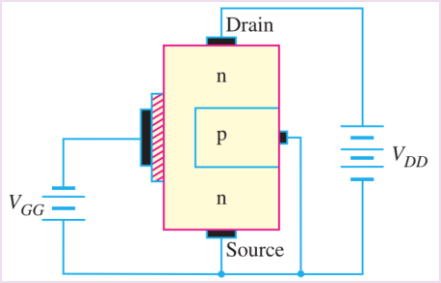


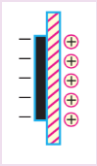


n-channel D-MOSFET

Circuit Operation of D-MOSFET

- The gate forms a small capacitor. One plate of this capacitor is the gate and the other plate is the channel with metal oxide layer as the dielectric.

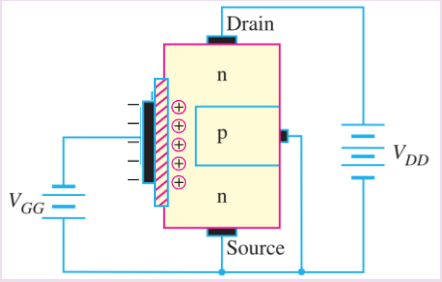




- When gate voltage is changed, the electric field of the capacitor changes which in turn changes the resistance of the n-channel.
- Since the gate is insulated from the channel, we can apply either negative or positive voltage to the gate. The negative-gate operation is called *depletion mode* whereas positive-gate operation is known as *enhancement mode*.

(1) Depletion mode

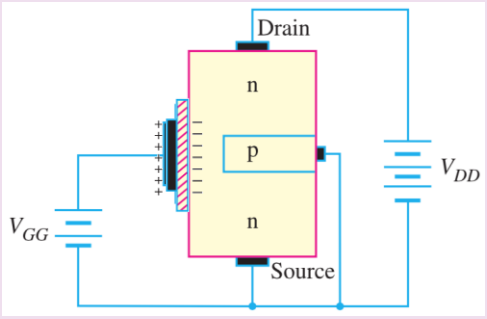
- The gate is negative.
- Electrons repel the free electrons in the *n*-channel, leaving a layer of positive ions in a part of the channel i.e. depleted the *n*-channel of some of its free electrons.
- Therefore the resistance of the channel is increased.
- By changing the negative voltage on the gate, we can vary the resistance of the *n*-channel and hence the current from source to drain.



Note: with negative voltage on the gate, the action of *D-MOSFET* is similar to *JFET*. Because the action with negative gate depends upon depleting the channel of free electrons, the negative-gate operation is called *depletion mode.*

(2) Enhancement mode

- The gate is positive.
- It induces negative charges in the *n*-channel.
- Because free electrons are added to those already in the channel, the total number of free electrons in the channel is increased.
- Thus a positive gate voltage *enhances* or *increases* the conductivity of the channel.
- By changing the positive voltage on the gate, we can change the conductivity of the channel.



Because the action with a positive gate depends upon *enhancing* the conductivity of the channel, the positive gate operation is called *enhancement mode.*

Some Remarks

(1) In a *D-MOSFET*, the source to drain current is controlled by the electric field of capacitor formed at the gate.

(2) The gate of *JFET* behaves as a reverse-biased diode whereas the gate of a *D-MOSFET* acts like a capacitor. For this reason, it is possible to operate *D-MOSFET* with positive or negative gate voltage.

(3) As the gate of *D-MOSFET* forms a capacitor, therefore, negligible gate current flows whether positive or negative voltage is applied to the gate. For this reason, the input impedance of *D-MOSFET* is very high, ranging from 10,000 MΩ to 1,000,000 MΩ.

(4) The extremely small dimensions of the oxide layer under the gate terminal result in a very low capacitance and the *D-MOSFET* has, therefore, a very low input capacitance. This characteristic makes the *D-MOSFET* useful in high-frequency applications.

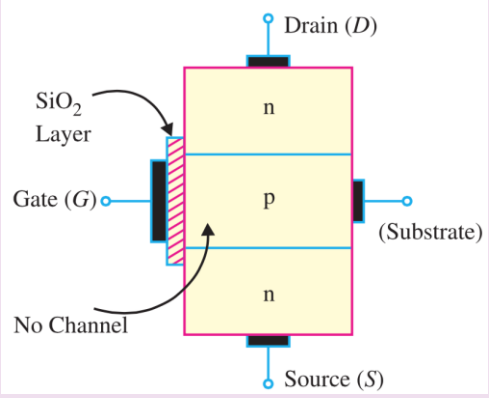
E-MOSFET

The *E-MOSFET* has no channel between source and drain unlike the *D-MOSFET*.

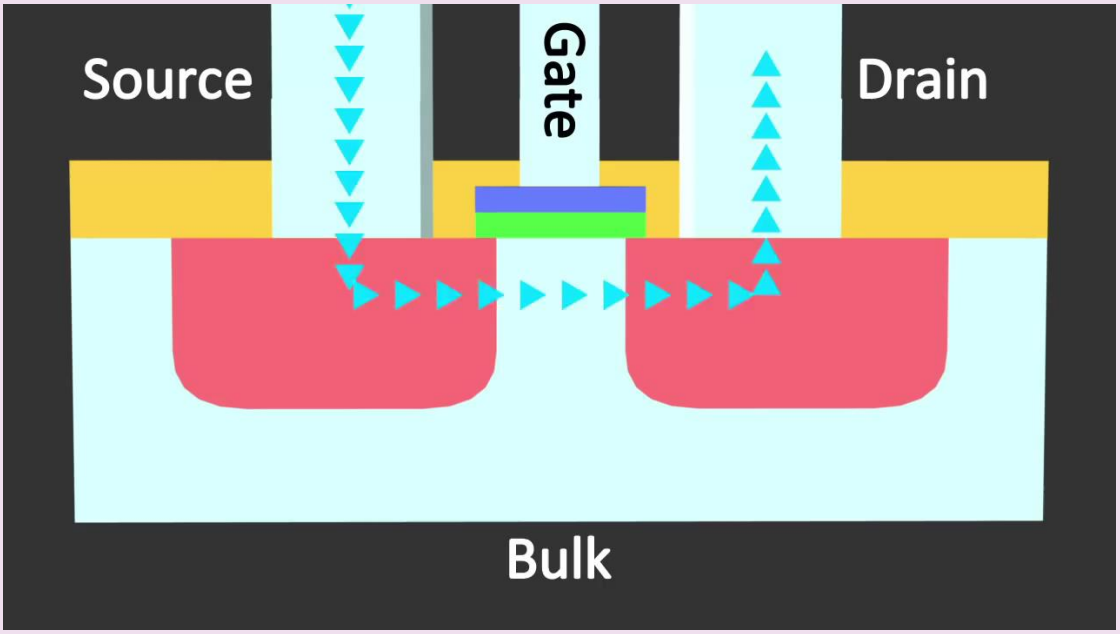
The substrate extends completely to the SiO_2 layer so that no channel exists.

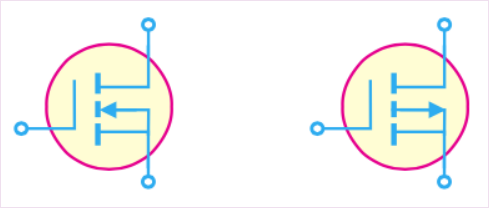
The *E-MOSFET* requires a proper gate voltage to *form* a channel (called induced channel).

It is reminded that *E-MOSFET* can be operated *only* in enhancement mode.



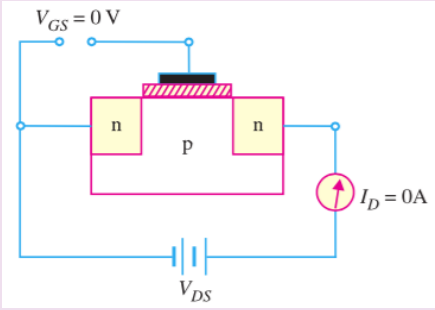
In short, the construction of *E-MOSFET* is quite similar to that of the *D-MOSFET* except for the absence of a channel between the drain and source terminals.





n-channel
E-MOSFET

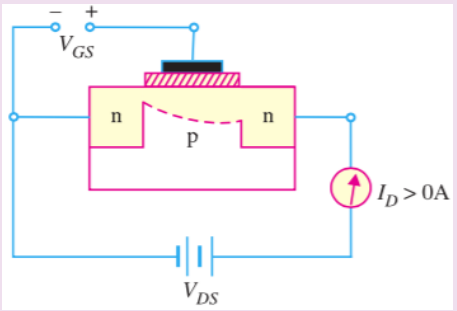
p-channel
E-MOSFET



- When V_{GS} = 0V, there is no channel connecting the source and drain.
- For this reason, *E-MOSFET* is normally *OFF* when V_{GS} = 0 V.

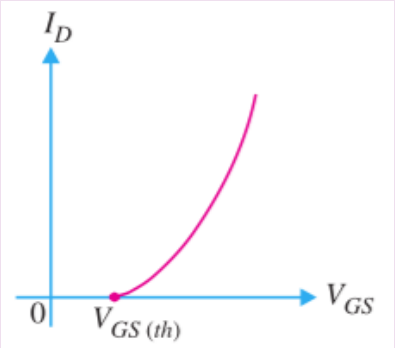
Note that this behavior of *E-MOSFET* is quite different from *JFET* or *D-MOSFET.*

- When gate is made positive, it attracts free electrons into the *p* region.
- The free electrons combine with the holes next to the SiO_2 layer.
- If V_{GS} is positive enough, all the holes touching the SiO_2 layer are filled and free electrons begin to flow from the source to drain.



The minimum value of V_{GS} that turns the E-MOSFET ON is called ***threshold voltage*** [$V_{GS\,(th)}$].

- When V_{GS} is less than $V_{GS\ (th)}$, there is no induced channel and the drain current I_D is zero.
- When V_{GS} is equal to $V_{GS\ (th)}$, the *E-MOSFET* is turned *ON* and the induced channel conducts drain current from the source to the drain.
- Beyond $V_{GS\ (th)}$, if the value of V_{GS} is *increased*, the newly formed channel becomes wider, causing I_D to increase.



The end